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BUREAU OF MINES
JOHN W. FINCH, DIRECTOR

INFORMATION CIRCULAR

TESTING AND DESIGN OF RESPIRATORY PROTECTIVE DEVICES

BY

H. H. SCHRENK

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

TESTING AND DESIGN OF RESPIRATORY PROTECTIVE DEVICES[1]

By H. H. Schrenk[2]

One phase of the Bureau of Mines' work in the field of health and safety is the promotion of the use of safe, satisfactory, and reliable respiratory protective devices. To promote the development of such devices the Bureau has established schedules of minimum requirements for oxygen breathing apparatus[3], gas masks[4], supplied-air respirators[5] (hose masks, airline respirators, and abrasive blasting helmets, hoods, or masks), and mechanical-filter respirators[6].

Manufacturers of respiratory protective devices may submit their equipment to the Bureau for approval under the requirements of these schedules.

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[1] The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Information Circular 7086." Presented at the Fifth International Conference of Directors in Mine Safety Research, Pittsburgh, Pa., Sept. 25-30, 1939.

[2] Chief chemist, Health Division, Bureau of Mines, U. S. Department of the Interior, Pittsburgh, Pa.

[3] Bureau of Mines, Procedure for Establishing a List of Permissible Self-Contained Mine Rescue Breathing Apparatus. Fees, Character of Tests, and Conditions Under Which Mine Rescue Breathing Apparatus Will Be Tested: Sched. 13, Mar. 5, 1919, 13 pp. Sched. 13A (revision of Schedule 13), January 21, 1930, 12 pp. Sched. 13B (revision of Schedule 13A), August 12, 1935, 12 pp.

[4] Bureau of Mines, Procedure for Establishing a List of Permissible Gas Masks. Fees, Character of Tests, and Conditions Under Which Gas Masks Will Be Tested: Sched. 14, May 22, 1919, 13 pp. Supplement to Sched. 14, Jan. 6, 1920, 4 pp. Sched. 14A (revision of Sched. 14), Aug. 25, 1923, 15 pp. Sched. 14B (revision of Sched. 14A), Aug. 7, 1930, 13 pp. Sched. 14C (revision of Sched. 14B), Aug. 20, 1934, 17 pp. Sched. 14D (revision of Sched. 14C), May 9, 1935, 17 pp.

[5] Bureau of Mines, Procedure for Testing Hose Masks for Permissibility: Sched. 19, Apr. 28, 1927, 8 pp. Supplement to Sched. 19, Aug. 20, 1934, 3 pp. Bureau of Mines, Procedure for Testing Supplied-Air Respirators for Permissibility: Sched. 19A (revision of Schedule 19 and supplement, enlarged to include special hose masks without blowers, airline respirators and abrasive blasting helmets, hoods, or masks), Aug. 9, 1937, 21 pp.

[6] Bureau of Mines, Procedure for Testing Filter-Type Dust, Fume, and Mist Respirators for Permissibility: Sched. 21, Aug. 20, 1934, 14 pp.

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As a prerequisite to such submittal, the Bureau requires a statement that the device is completely developed and of the design and material the manufacturer believes suitable for a finished marketable device; that the device has been subjected to inspections and tests such as described in the schedules, and that it met those requirements when tested by the manufacturer or his testing agency; and a statement regarding the nature, adequacy, and continuity of control of the quality of the respirator. If the manufacturer can satisfy these requirements, and if the device, when tested by the Bureau, meets its requirements, a certificate of approval is granted by the Bureau of Mines. The approved devices bear distinguishing marks that indicate that they have been approved, the purpose for which they are approved, and the limitations of their use. If it is found at any time that approved devices purchased in the open market and tested do not meet the requirements of the schedule, the Bureau may rescind that approval. Lists[1] of approved devices are published periodically for the convenient information of the public.

CLASSIFICATION OF RESPIRATORY EQUIPMENT

Respiratory equipment may be divided into two main groups: (1) Those that afford protection by removing atmospheric contaminants and (2) those by which a respirable atmosphere from an uncontaminated source is supplied to the wearer.

The devices that protect by the removal of contaminants may be divided into two subgroups: (1) Those that protect against gaseous contaminants and (2) those that protect against particulate matter. There may, of course, be combinations of these two.

The devices by which a respirable atmosphere is furnished to the wearer also may be divided into two subgroups: (1) The self-contained type, by which the supply of oxygen, or material from which the oxygen can be generat is carried by the wearer, and (2) the hose type, by which air is supplied to the wearer through a hose or tube.

Various modifications of the respiratory devices are available in the groups listed. For example, there are four types of oxygen breathing apparatus - half-hour, three-quarter hour, one-hour, and two-hour. There are also various supplied-air types that differ in design and consequently i field of use. There are various modifications of the respirators that are designed to remove particulate matter by mechanical filtration. The respira tory equipment designed for protection against gaseous substances differs a regards the kinds of gaseous material it removes or renders harmless.

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[1] Schrenk, H. H., List of Respiratory Protective Devices Approved by the Bureau of Mines: Inf. Circ. 7030, July 1938, revised February 1939, 9 pp.

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OXYGEN BREATHING APPARATUS

Self-contained oxygen breathing apparatus has been described[8] in detail elsewhere and will not be discussed in this report. The essentials of the approval requirements - efficiency, service life, comfort, and durability - are the same as for the other respiratory equipment. The most significant progress in the improvement of this type of apparatus has been toward decreasing the weight. This apparatus is tested by the Safety Division of the Health and Safety Branch of the Bureau of Mines; the other devices are tested by the Health Division.

SUPPLIED-AIR RESPIRATORS (HOSE MASKS)

Supplied-air respirators are classified in Schedule 19A as type A, type B, type C, and types AE, BE, and CE. Owing to the limited use of supplied-air respirators in mines, they are discussed briefly.

The type A supplied-air respirator is commonly called hose mask. Its principal parts are a hand-operated blower that allows free entrance of air to the hose when the blower is not operated, a strong, large-diameter hose having a low resistance to air flow, a harness to which hose and life line are attached, and a tight-fitting facepiece.

The type B supplied-air respirator is essentially the same as the type A, with the main exception that it has no blower.

The type C supplied-air respirator is commonly called airline respirator. Its principal parts are a positive-pressure air-supply system, a hose, and a respiratory-inlet covering. The term "respiratory-inlet covering" is used for the covering worn over the face or head by the wearer of the respirator, when otherwise it would be necessary to use an expression such as "facepiece", "half facepiece", "helmet", or "hood."

Types AE, BE, and CE supplied-air respirators are primarily the same as types A, B, and C, except that they have been modified for use in abrasive blasting. The modifications consist essentially of providing a suitable covering, hood, or helmet to protect the head and shoulders against impact and abrasions by the rebounding material.

The type C supplied-air respirator or airline respirator is the only one of this group that has been used to any extent in mining, and its use has been limited. In some of the metal mines of the United States the type C supplied-air respirator has been used during drilling. The air is generally warmed and humidified for comfort. The device is particularly desirable in high concentrations of dust that would tend to plug the dust respirators so rapidly that they would be impractical. Although one might consider the airlines a handicap, apparently the men become accustomed to them and frequently ask for them once they have used them.

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[8] Parker, D. J., McKay, G. S., and Denny, E. H., Self-Contained Oxygen Breathing Apparatus: Handbook, U. S. Dept. of the Interior, Bureau of Mines, 1934. Revised by G. W. Grove.

The type A supplied-air respirators (hose masks) are used widely for entering tanks, manholes, sewers, or other confined spaces such as holds in ships, where there is danger of high concentrations of harmful contaminants or the possibility of a deficiency of oxygen. The type B device is used in situations similar to those for type A, except that its field of use is more limited and restricted to the less dangerous operations because it does not have a positive supply of air.

Types AE, BE, and CE are used for protection during abrasive blasting, as in foundries.

Approval Tests

In testing the supplied-air respirators (hose masks) for approval, consideration is given to the air-supply line, harness, breathing tubes, and respiratory-inlet covering. All of these must be satisfactory for the purpose designed. In type A the blower is tested also for durability, amount of air supplied, and power requirements. As a final test the complete device is worn for 10 minutes in 1 percent ammonia. To meet the requirement of this test, no ammonia shall be detected in the air breathed and no undue encumbrance or discomfort shall be experienced because of the fit, air delivery, or other features of the respirator. The complete respirator is worn also in an atmosphere containing 50 ± 10 milligrams per cubic meter of ground flint. During the test period of 30 minutes, air at the rate of 32 liters per minute is withdrawn continuously and simultaneously from the respiratory-inlet covering and air-supply line. The amount of dust collected from the respiratory-inlet covering shall not exceed that collected from the air-supply line by more than 0.5 milligram.

GAS MASKS

Gas masks are designed to remove gaseous contaminants by sorption or by chemical reaction. They consist essentially of a facepiece and canister. Other essential parts in some types are a harness for carrying the canister and a breathing tube. The breathing-tube types are used mainly in this country while the masks with the canisters attached directly to the facepiece are used more commonly in European countries.

Gas masks are divided into various types, depending on the contaminant or contaminants against which they are designed to protect. Type A is designed for protection against acid gases such as chlorine, formic acid, hydrogen chloride, hydrogen cyanide, hydrogen sulfide, phosgene, and sulfur dioxide. Type B is designed for protection against organic vapors such as acetone, alcohol, aniline, benzene, carbon bisulfide, carbon tetrachloride, chloroform, ether, formaldehyde, gasoline and petroleum distillates, and similar volatile compounds. Type C is for protection against ammonia, and type D for protection against carbon monoxide. Type E is for protection against dusts, chemical smokes, fumes, and mists, such as tin tetrachloride, silicon tetrachloride, titanium tetrachloride, and sulfur trioxide. Type F is for protection against other special gases. Types AB, ABC, etc., are for protection against combinations of the preceding types. Type N is for protection against combinations to include all of the preceding types. A olor code has been adopted by the Bureau of Mines whereby canisters designed for different gases are assigned a specific color. For example, the ll-service gas mask canister is red and the self-rescuer is blue.

The Bureau of Mines is concerned only with industrial respiratory equipment and not with military equipment.

Approval Testing

The essentials that are considered in addition to design, durability, nd practicability of construction are efficiency and life of the canister, tability of the absorbents, and gas-tightness of the entire respiratory ssembly including facepiece.

The procedure in testing canisters for protection against gases other han carbon monoxide is briefly as follows: The canisters are tested in the aboratory against at least two different concentrations of the gas and gainst at least two rates of flow of the test atmosphere. They are tested s received and also after equilibration for 6 hours with air having a elative humidity of 25 percent and with air having a relative humidity of 5 percent. These tests are made to ascertain the chemical stability of the bsorbents. After the laboratory tests are completed, the gas masks are orn by two or more persons doing moderately heavy work in the maximum concentration of gas for which the equipment will be approved. The life of the anister during this test must be a minimum of 30 minutes. Canisters are pproved for a maximum of 2 percent by volume of gas, except the ammonia anister, which is approved for 3 percent.

The resistance of canisters shall not exceed 3 inches of water, and the esistance of the entire assembly shall not exceed 3.5 inches of water.

The all-service canister is described in detail in Miners' Circular 35[2]. he detailed tests of the all-service canister for protection against carbon onoxide are as follows: Three canisters are tested against a concentration f 1 percent carbon monoxide at a rate of 32 liters per minute. The minimum ervice period is 240 minutes. The maximum leakage of carbon monoxide peritted during this period is 960 ml.

In a second test, three canisters are immersed in an ice-water bath and ested at a concentration of 0.5 percent carbon monoxide at a rate of 32 iters per minute. The relative humidity of the gas entering the canister s 100 percent at the temperature of the test. The minimum service period equired is 60 minutes, and the allowable leakage of carbon monoxide through e canister is 960 ml.

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[2] Forbes, J. J., and Grove, G. W., Protection Against Mine Gases: Bureau of Mines Miners' Circ. 35, 1937, 52 pp. 17 figs. (Revision of Miners' Circ. 35, Advanced Mine Rescue Training. Part III. Protection Against Gases Encountered in Mines.)

In a third test, two canisters are tested at a concentration of 2 percent carbon monoxide at a rate of 64 liters per minute. The minimum service period is 15 minutes and the maximum allowable leakage of carbon monoxide is 960 ml. The canister is approved for a maximum concentration of 2 percent carbon monoxide.

Another device for protection against carbon monoxide is the so-called self-rescuer. This is a pocket size gas mask designed to help miners escape at times of mine fire or explosion by providing temporary protection from carbon monoxide. It is tested as follows: A 1-percent concentration of carbon monoxide is passed through the canister at a rate of 32 liters per minute. The minimum service period is 60 minutes and the maximum allowable leakage is 640 ml. of carbon monoxide. In a second test at 0° C. a concentration of 0.5 percent of carbon monoxide is passed through the self-rescuer at a rate of 32 liters per minute. The minimum service period is 30 minutes and the maximum leakage shall not exceed 640 ml.

Concentrations of 1 to 2 percent carbon monoxide generate enough heat on oxidation to raise the temperature of the canister to an uncomfortably high degree, and the effluent air becomes quite hot. It would probably be difficult to wear the mask longer than 20 to 30 minutes in 2 percent carbon monoxide owing to the effect of the hot dry air on the mucous membranes.

The life of the canister and self-rescuer depends on the life of the drying agent that protects the catalyst, since moisture decreases the efficiency of the catalyst for oxidizing carbon monoxide.

MECHANICAL-FILTER RESPIRATORS

Mechanical-filter respirators are based on the principle that particula matter is retained when air is passed through a filter of fibrous or other suitable material. This type of respirator probably is the simplest, lighte cheapest, and most used of all the respiratory protective devices.

Most mechanical-filter respirators consist of a filter of a fibrous or other suitable material in a holder connected directly to a half facepiece that covers the nose and mouth. The filter holders or filter elements may b divided into two groups - those in which the filter holder or filter element is attached to each side of the facepiece and those in which a single felt holder or filter element is attached to the front of the facepiece. The filter holders or filter elements are designed so that the filter may be removed readily for cleaning or replacement by a new filter.

The respirator may or may not have inhalation and exhalation valves. All but one of the approved respirators have exhalation valves and the majority have inhalation valves. The concensus of opinion of those well acquainted with the mechanical-filter respirators is that both exhalation and inhalation valves are desirable.

Mechanical-filter respirators are divided into three groups, depending on the character of particulate matter against which they are designed to

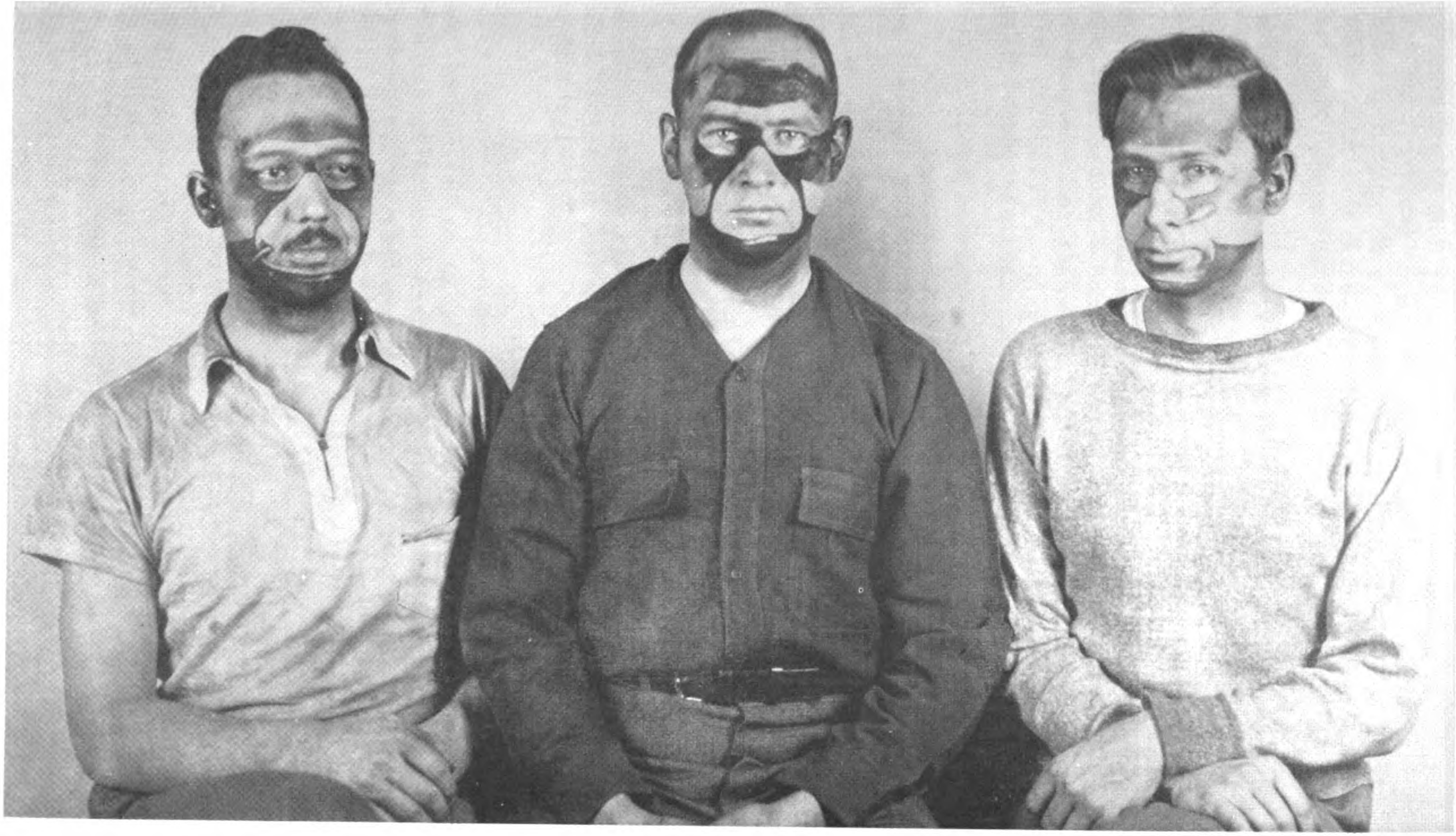

Figure 1.- Results of coal-dust test for fit of dust-respirator facepieces.

protect. Type A is for protection against dust generated by disintegration as in drilling and blasting; type B is for protection against fumes such as are generated in lead burning; and type C is to be used against mists such as are formed in electroplating and spray-painting. The discussion in this report will be confined mainly to type A or dust respirators for protection against pneumoconiosis-producing dusts such as free silica and asbestos, and nuisance dusts such as aluminum, iron ores, and flour. However, much interest has been shown in respirators for protection against lead dust and lead fume.

Approval Testing

The general approval requirements are that the respirators must give dequate protection with reasonable comfort for a satisfactory time in any tmosphere for which they are designed. In addition to examining the espirator for design, durability, and practicability, three main tests are ade to ascertain efficiency, resistance, and fit of the facepiece.

Direct Leakage and Man Test

The facepiece fit of the respirator is tested by blowing air containing high concentration of coal dust toward respirators worn by three subjects, ach with a different type of face (lean, average, and full). Figure 1 shows he results of such a test, in which leaks were intentionally caused under he respirators worn by the subjects on the right and left by inserting a oothpick under the facepiece at the places indicated by the white streak. he respirator apparently fitted the middle subject properly. Inasmuch as acepiece fit is one of the important requirements of mechanical-filter espirators from the standpoint of practical application, such a test as escribed might well be used in teaching persons to wear the respirators roperly and to impress upon them the significance of proper fit of a face-iece. This test also indicates very quickly the inadequacy of some of the oorly designed respirators.

Resistance to Air Flow

In the gas mask, the contaminants may be removed satisfactorily for a ertain time, after which efficiency drops rapidly and the mask is no longer atisfactory for protection. In the mechanical-filter respirator, however, he filter increases in efficiency as the contaminant is removed, and the imiting factor is not the efficiency of the filter but the resistance to in-alation. The service life of a suitable mechanical-filter respirator, herefore, is not based on filtering efficiency, but on resistance. The esistance to inhalation is limited to a maximum of 50 millimeters of water-olumn height at 85 liters per minute after the respirator has been tested nd loaded with dust. The resistance to exhalation is limited to a maximum f 25 millimeters at the same rate of flow. The respirator should give atisfactory service without cleaning or changing the filter element for bout 8 hours in any atmosphere that does not contain an excessively high oncentration of dust. In other words, the resistance of the respirator ust not increase unduly before a reasonable amount of dust is retained. The use of mechanical-filter respirators in the immediate vicinity of operations such as abrasive blasting with dry sand or rock drilling with dry-type pneumatic drills is impractical due to the rapid increase in resistance to breathing caused by excessive amounts of dusts retained by the filter.

Filtering-Efficiency Test

The filtering-efficiency test consists mainly of testing three or more respirators on a mechanical testing apparatus against a high concentration of dust whose properties are similar to those for which the respirator is to be approved. The test atmosphere is pulled through the respirator at the rate of 32 liters per minute. The concentration of dust in the chamber and the amount of dust that leaks through the respirator is collected by electric precipitation and weighed on an analytical balance. The preparation of the test atmosphere and sampling is described in detail later.

Table 1 gives the detailed requirements of the filtering efficiency test for pneumoconiosis-producing or nuisance dusts. The filtering-efficiency tests are based on the so-called safe or permissible limits. From data available, 1 milligram of silica dust per cubic meter, or approximately 8 million particles per cubic foot, is considered safe to breathe. Therefore, if the air passing through the respirator does not contain more than this amount, it is considered safe. In other words, the permissibility of the respirator is based primarily on the amount of leakage and not on the relation between leakage and amount retained.

TABLE 1. - Test conditions and filtering requirements of respirators for protection against pneumoconiosis-producing or nuisance dust.

Concentration, mg/m^3	Air flow, l/m	Test period, minutes	Volume of air through respirator	No. of respirators	Approximate dust load, mg	Allowable leakage, mg
50 ± 10	32	90	2.9	3	145	3 mg. average for 3 respirators or 4 mg. for any one.
5 ± 2	32	312	10	3	50	10 mg. average for 3 respirators or 12 mg. for any one.

Preparation of Test Atmosphere

Dusty atmospheres for testing filtering efficiency of the respirators are prepared by feeding dust into air at a constant rate. The dust-laden air is passed through settling chambers or a cyclone to remove the larger particles. By varying the rate at which the air is pulled through the settling chamber or through the test chamber and cyclone, particle size of the dust can be regulated as desired and maintained reasonably close to the chosen size over a period of time. The dust used in testing pneumoconiosis-

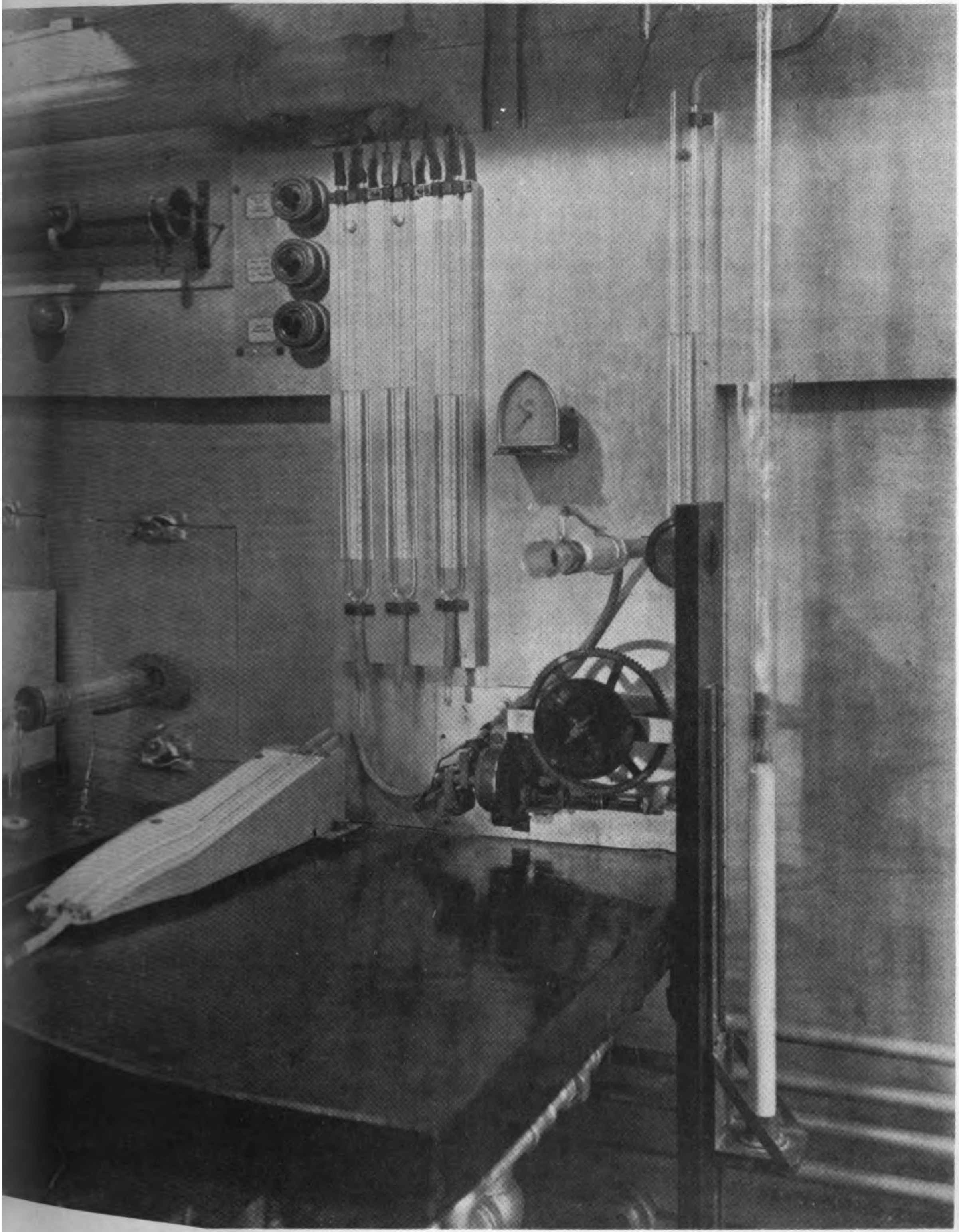

Figure 2.- Apparatus for preparing dusty atmospheres.

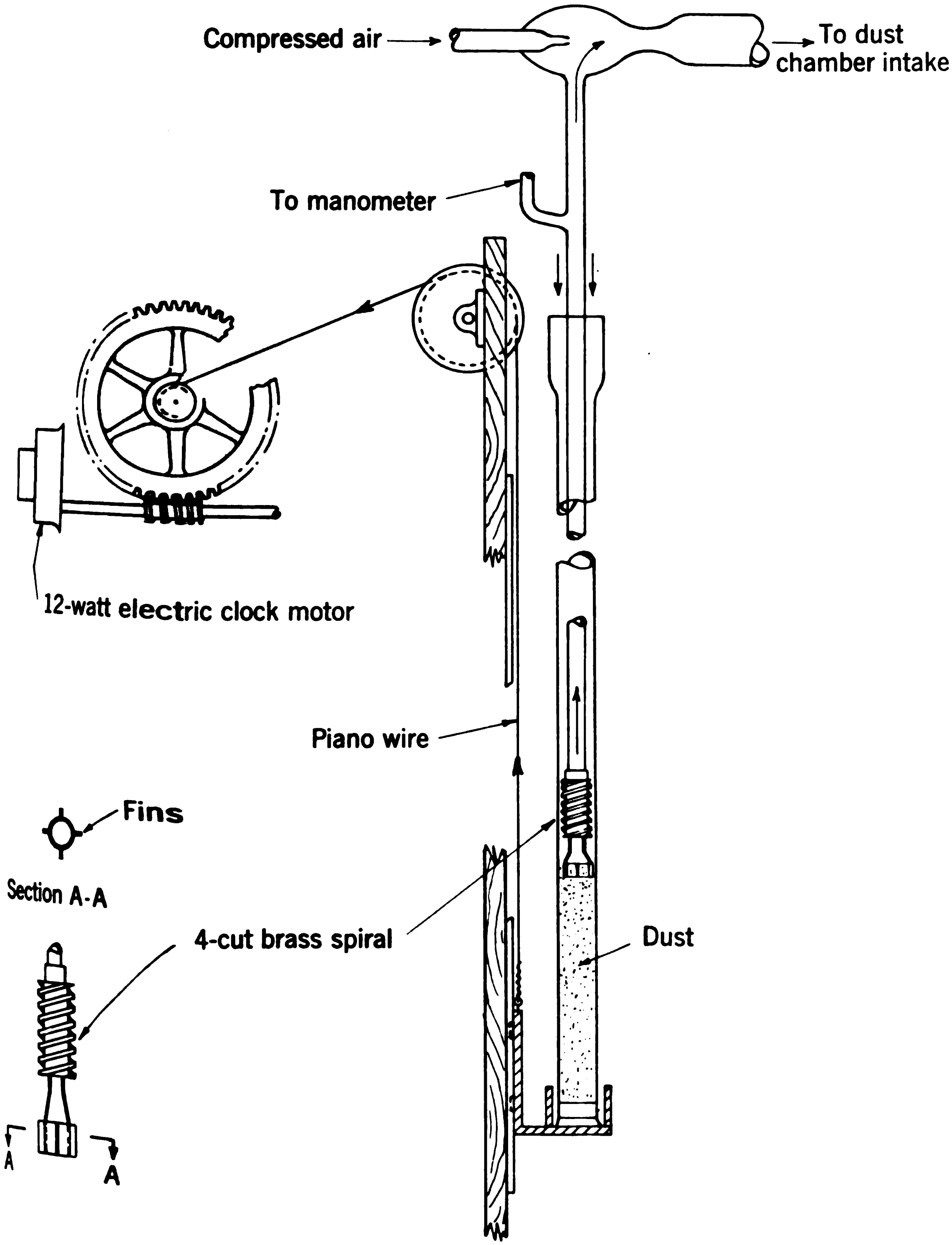

Figure 3.- Dust feed apparatus.

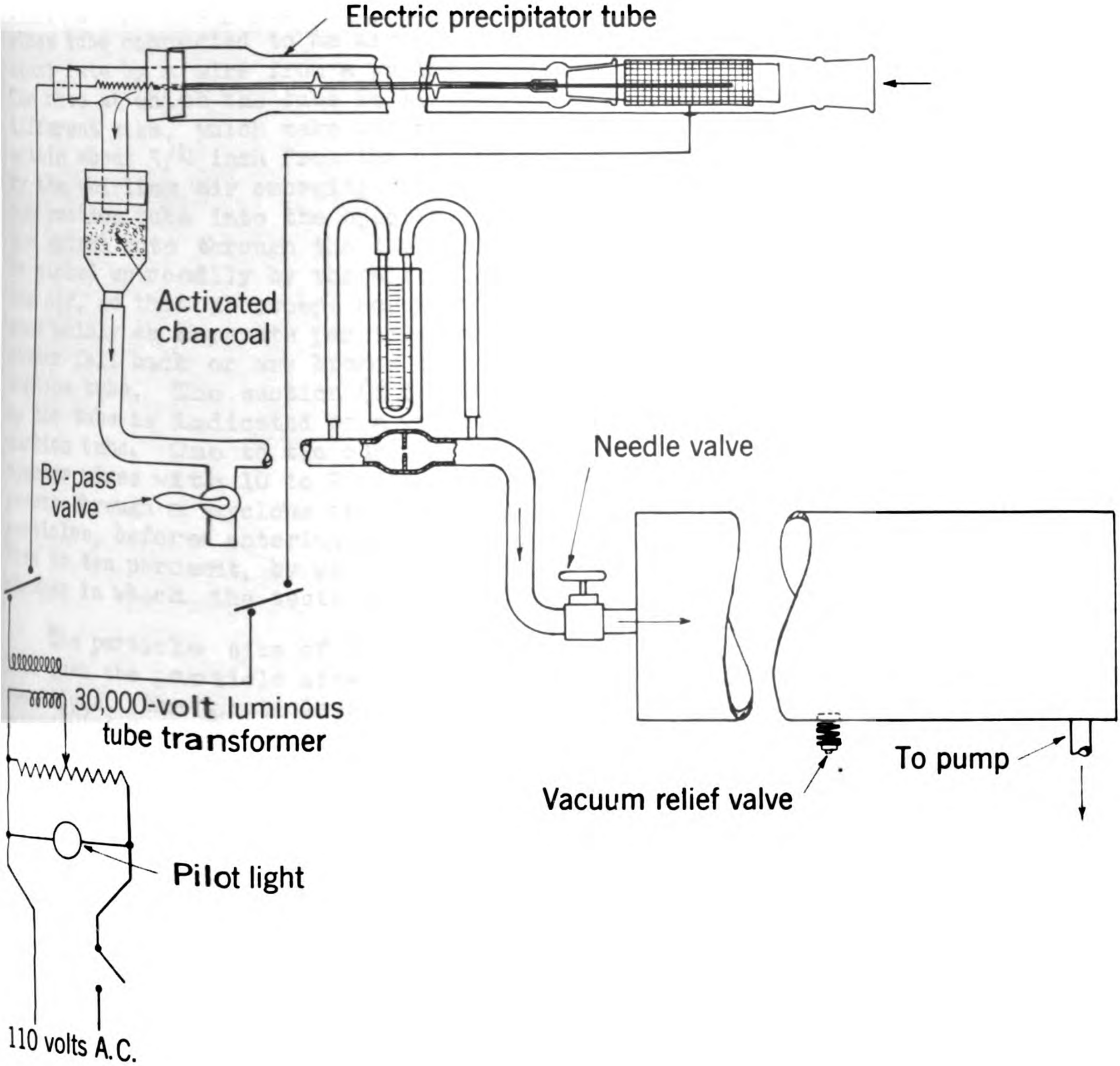

Figure 4.- Dust-sampling apparatus.

producing and nuisance dust (type A) respirators is 99+ percent free SiO_2 and of such fineness that over 99 percent passes through a 325-mesh sieve. When packed into the dust tube by tapping and allowed to stand for several hours, the dust has a density of about 1 gram per ml. Figure 2 is a photograph of the apparatus employed in preparing dusty atmospheres, and figure 3 is a sketch of the apparatus used to feed dust into the air at a constant rate. A vertical glass tube containing the dust is pulled up around a rigid glass tube connected to an air ejector. The dust tube is raised at a constant rate by a wire from a pulley driven by a 12-watt electric clock motor. The rate at which the tube is lifted may be varied by the use of pulleys of different size, which make one revolution in 100 minutes. As the dust comes within about 3/4 inch from the bottom of the suction tube, it is picked up by the whirling air emerging from the four-cut brass spiral and carried by the suction tube into the ejector. The thin-walled cylinder attached below the spiral cuts through the dust column and loosens the dust so that it can be picked up readily by the air. The spiral imparts a whirling motion to the air, so that it sweeps across the top of the dust column, picking up the dust mainly as separate particles rather than lumps. Any lumps picked up either fall back or are broken in the whirling air before entering the suction tube. The suction (a few inches of water) required to draw the dust up the tube is indicated on a water manometer connected to a side arm on the suction tube. One to two cubic feet per minute of the dusty air from the ejector mixes with 10 to 20 times its volume of electrically cleaned air and passes through a cyclone or settling chamber, for removal of the larger particles, before entering the chambers in which the respirators are tested. Five to ten percent, by weight, of the dust fed into the air reaches the chamber in which the tests are conducted.

The particle size of the dust used in testing is equal to or slightly less than the particle size of dust generally found in mining and industrial operations. The particle-size measurements were made by the microprojection method[10] developed by the Bureau of Mines. Particles in the air used for testing usually have a geometric mean of about 0.6 micron and a standard geometric deviation of 1.9.

Sampling and Determination of Dust

All samples of dust for the determination of concentration in both the test atmosphere and the air pulled through the respirator during tests are collected by electrical precipitation, which is probably the most efficient method for removing dust from air.

Figure 4 is a sketch of the sampling arrangement. Dusty air from the chamber or from the interior of the respirator is pulled, at the rate of 32 liters per minute, through the electric precipitator in which the dust is precipitated or collected on a small glass tube. The effluent air passes through activated charcoal to remove ozone that otherwise would attack the rubber connections, then through the orifice of a flow meter, and finally through a surge tank, which decreases fluctuations in the air flow.

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[10] Brown, Carlton E., Baum, Lester A. H., Yant, William P., and Schrenk, Helmuth H., Microprojection Method for Counting Impinger Dust Samples: Bureau of Mines Rept. of Invest. 3373, January 1938, 9 pp.

Figure 5 is a sketch of the electric precipitator tube and the device for holding the respirator during the test. The respirator holder consists of a curved brass sheet having an opening into which is attached the male part of a standard, pyrex No. 25, ground-glass joint. A respirator is attached over the opening in the holder by sealing the edges of the respirator facepiece to the holder with a molten mixture consisting of 1 part Venice turpentine and about 25 parts, by weight, of sealing wax. The tightness of the seal is tested by tobacco smoke or soapsuds. The dust sample is collected on the inner wall of a sampling tube and to a small extent on the central electrode of 18-gage nichrome or stainless-steel wire. The central electrode slips into a stainless-steel socket. The tube and electrode can be removed readily from the precipitator and a new set put in place. The voltage of the precipitator is adjusted to just below the arcing value by regulating the primary voltage by an adjustable rheostat in the primary circuit of the transformer. The arcing voltage of the precipitator is about 20,000 volts. The amount of dust collected is determined by weighin the tubes on an analytical balance. For other purposes, however, the dust can be washed from the tube and counted or analyzed chemically.

Discussion

Data obtained in approval-testing of dust respirators indicate that most of the dust is retained by the filter on or near the first surface contacted by the dust. Filtering efficiency varies with particle size of dust and increases with amount of dust retained. When the same kind of fibrous material is used, filtering efficiency tends to vary directly with resistance to flow of air. Resistance to the flow of air varies almost directly with rate of flow and inversely with the area of the filter. Although resistance increases with amount of dust retained, usually it returns nearly to its initial strength if the fibrous material is cleaned by shaking it or blowing air through it.

At the time Schedule 21[11] was published, no respirator that would pass the schedule was available in this country. The importance attached to the Bureau's approval was an incentive for companies to spend considerable time and effort in developing respirators that would pass this schedule. As a result, the quality and number of dust respirators have increased markedly since the approval schedule was issued. The filtering efficiency of approve respirators is higher, the resistance to air flow lower, filter area is greater, fit of facepiece better, dead air space smaller, durability greate and cost about the same. Twenty-eight approvals have been granted to date. In addition to the fact that the schedule and the Bureau's testing have bee of great value in the development of dust respirators, the users of these devices also have been benefited greatly in that they are able to obtain respirators they know will serve the purpose for which they were designed.

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[11] See footnote 6, p. 1.

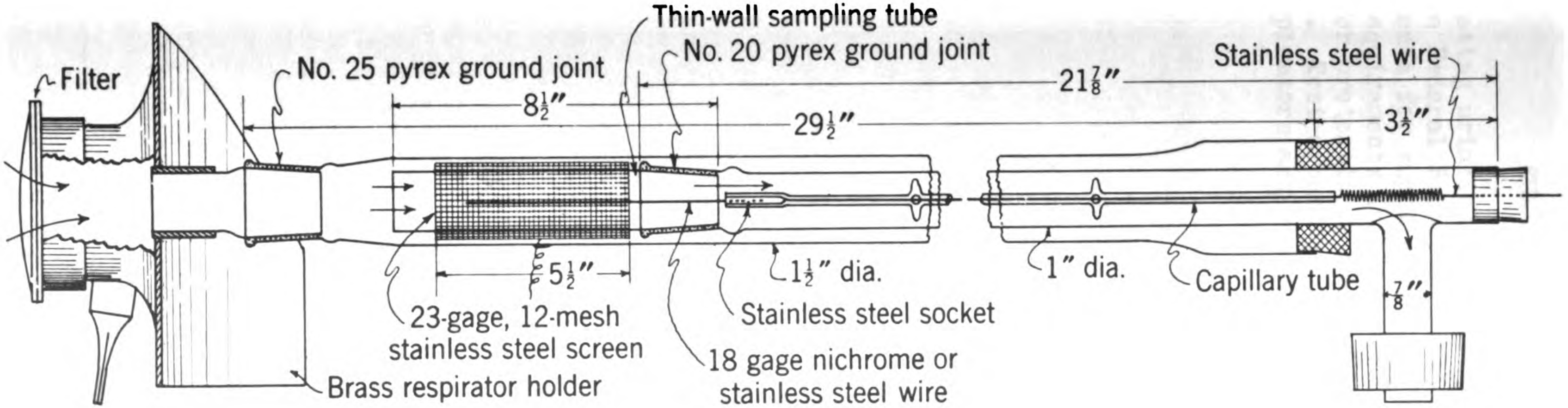

Figure 5.- Electric-precipitator dust-sampling tube.

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SUMMARY

The design and operating principles of the various types of respiratory equipment approved by the Federal Bureau of Mines are described. Bureau of Mines' approval requirements for supplied-air respirators (hose masks) are presented briefly; the requirements for gas masks also are presented briefly, except those for masks for protection against carbon monoxide, which are described in some detail. Test apparatus, test procedure, and approval requirements of dust respirators are described in detail.